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# Strength and Cost Of Natural and Portland Cement Concretes

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# STRENGTH AND COST OF NATURAL AND PORTLAND CEMENT CONCRETES

...BY...

Fred Henry Burgess

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THESIS FOR THE DEGREE OF BACHELOR OF SCIENCE
IN CIVIL ENGINEERING

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COLLEGE OF ENGINEERING
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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

FRED HENRY BURGESS

ENTITLED STRENGTH AND COST OF NATURAL AND PORTLAND CEMENT CONCRETES.

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF Bachelor of Science in Civil Engineering.

Ira O. Baker.

HEAD OF DEPARTMENT OF Civil Engineering.

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# Strength and Cost of Natural and Portland Cement Concretes.

The experiments described in this thesis were made for the purpose of determining the relative strength and relative cost of natural- and portland-cement concrete. This has lately become an important question, as the decrease in price of portland cement has made it a competitor of the natural cement for all kinds of concrete in which natural cement can be used. The only other experiments known to the writer along this line were made by Mr. O. L. Gearhart, City Eng. of Champaign, Ill., to determine the strength and cost of natural- and portland-cement concretes made of different mixtures of gravel and broken stone. Mr. Gearhart's cheapest portland-cement

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concrete, consisting of 1 part cement to 10 parts each of gravel and broken stone, had very nearly the same strength and cost as a natural-cement concrete consisting of 1 part cement to 3 parts each of gravel and broken stone.

## Description of Experiments.

The experiments herein described consisted in testing 6-inch cubes and 6 x 6 x 21-inch beams. Nine cubes were made for each proportion of concrete, three of each proportion being crushed at 7, 30, and 90 days. Beams were made for the natural-cements concrete and for the leaner portland-cement concretes, and were tested at 30 and 90 days.

The cements were Alpha portland and Louisville Star natural, and are thought to be

fair representatives of their respective classes. The sand was obtained from the Wabash river near Attica, Ind., and had been thoroughly washed at the pit. It contained but little fine material, and had 36.4 percent of voids. The crushed stone was a coarse-grained limestone obtained at Kankakee, Ill. It had been screened to remove fragments larger than an inch and smaller than 1/4 inch, and had 44.5 percent of voids.

Preliminary tests were made to determine the tensile strength of the neat cements. Briquettes were made by hand and with the Boehme hammer. They were allowed to stand 24 hours in air, were then placed under water, and were broken at the age of 7 days. The results are given in Table I.

# TABLE I.

## TENSILE STRENGTH OF THE CEMENTS.

Pounds per square inch. Age—7 days.

| REF. NO. | STAR NATURAL | | ALPHA PORTLAND | |
|---|---|---|---|---|
| | HAND Water = 31% | BOEHME Water = 28.5% | HAND Water = 23% | BOEHME Water = 14% |
| 1 | — | 250 | 735 | 1050 |
| 2 | 140 | 250 | 755 | 1035 |
| 3 | 135 | 250 | 760 | 1275 |
| 4 | 125 | 235 | 695 | 1280 |
| 5 | 130 | 235 | 725 | 1330 |
| AVERAGE | 132 | 245 | 734 | 1194 |

The cubes were molded in forms made of 1 3/4-inch oak lumber, rigidly bolted at the ends, each form holding three cubes. The beams were made by removing the two interior partitions of the forms. The concrete was proportioned by volume, the cement and sand being measured loose. The percent of water used varied with the ratio of the volume of the mortar to the volume of the stone. It was found that for proportions in which the mortar was less than 53 per cent of the volume of the stone, an excess of water caused a considerable loss of mortar, as the concrete was so porous that the water escaped freely at the bottom of the molds, carrying much mortar with it. For these proportions, the concrete was mixed dry enough to allow no water to flush to the

top; but for proportions in which the volume of mortar exceeds 50 per cent of that of the stone, the concrete was what is commonly called medium wet, as much fluxed to the top under tamping.

The forms were filled in 2-inch layers or one third of the depth at a time, each layer receiving fifty blows from an 11-pound tamper dropped 4 to 6 inches. A beam received one hundred and fifty blows for each layer. The cubes were allowed to stand in air 48 hours and were then placed in water. They were crushed in a Philadelphia testing-machine running at the slowest speed, the loading applied in a direction normal to the layers of the cube. To secure even bedding, the top and bottom faces of each cube

were coated with plaster-of-paris, which was allowed to set under a pressure equal to about one sixth of the estimated crushing strength of the cube. The results of these experiments are given in Table II.

From an inspection of Table II, it will be noticed that the leanest portland-cement concrete is stronger than the rich natural-cement concrete. The experiments were planned with the expectation that the leanest portland concretes would be considerably weaker than the natural-cement concrete; and when it was found that such was not the case, it was impracticable to make additional tests.

The beams were tested by placing them upon supports 18 inches apart and applying the load at the center, by means

# TABLE II.

## STRENGTH AND COST OF CONCRETE.

| No. | PROPORTIONS | | | AGE, DAYS | AVERAGE MAX. LOAD ON CUBES | AVERAGE CRUSHING STRENGTH LBS. PER SQ. IN. | BEAMS | | YIELD IN TERMS OF BROKEN STONE | COST DOLLARS PER CU. YD. |
|---|---|---|---|---|---|---|---|---|---|---|
| | CEMENT | SAND | BROKEN STONE | | | | LOAD AT CENTER LBS. | MOD. OF RUPTURE LBS. PER SQ. IN. | | |
| | | | | NATURAL CONCRETE | | | | | | |
| 1 | 1 | 2 | 4 | 7 | 9700 | 270 | | | 117 % | 2.26 |
| 2 | | | | 30 | 20000 | 560 | 1450 | 181 | | |
| 3 | | | | 90 | | | | | | |
| | | | | PORTLAND CONCRETE | | | | | | |
| 4 | 1 | 3 | 5 | 14 | 61600 | 1700 | | | 120 % | 3.64 |
| 5 | | | | 30 | 82800 | 2300 | | | | |
| 6 | | | | 90 | 81700 | 2270 | | | | |
| 7 | 1 | 3 | 6 | 14 | 60900 | 1690 | | | 115 | 3.37 |
| 8 | | | | 30 | 66200 | 1840 | | | | |
| 9 | | | | 90 | 83000 | 2300 | | | | |
| 10 | 1 | 3 | 7 | 14 | 41150 | 1140 | | | 110 | 3.19 |
| 11 | | | | 30 | 53000 | 1470 | | | | |
| 12 | | | | 90 | 55900 | 1550 | | | | |
| 13 | 1 | 3 | 8 | 14 | 37100 | 1030 | | | 108 | 2.99 |
| 14 | | | | 30 | 39500 | 1100 | | | | |
| 15 | | | | 90 | 52000 | 1440 | | | | |

# TABLE II. (Continued)

| No. | Proportion | | | Age Days | Average Max. Load on Cubes | Average Crushing Strength Lbs. per Sq. In. | Beams | | Yield in Terms of Broken Stone | Cost Dollars per Cu. Yd. |
|---|---|---|---|---|---|---|---|---|---|---|
| | Cement | Sand | Broken Stone | | | | Load at Center Lbs. | Mod. of Rupture Lbs. per Sq. In. | | |
| 16 | 1 | 4 | 6 | 7 | 40700 | 1130 | | | 120% | 3.32 |
| 17 | | | | 30 | 62000 | 1720 | | | | |
| 18 | | | | 90 | 69300 | 1925 | | | | |
| 19 | 1 | 4 | 7 | 7 | 32800 | 910 | | | 115 | 3.15 |
| 20 | | | | 30 | 58800 | 1630 | | | | |
| 21 | | | | 90 | 70300 | 1950 | | | | |
| 22 | 1 | 4 | 8 | 7 | 26500 | 735 | | | 111 | 3.00 |
| 23 | | | | 30 | 53800 | 1500 | | | | |
| 24 | | | | 90 | 62200 | 1730 | | | | |
| 25 | 1 | 4 | 9 | 7 | 25000 | 700 | | | 108 | 2.88 |
| 26 | | | | 30 | 41600 | 1160 | | | | |
| 27 | | | | 90 | 47100 | 1300 | | | | |
| 28 | 1 | 4 | 10 | 7 | 25800 | 720 | | | 105 | 2.79 |
| 29 | | | | 30 | 33400 | 930 | | | | |
| 30 | | | | 90 | 34150 | 950 | | | | |

# TABLE II (Continued)

| No. | Proportion | | | Age | Average Max. Load on Cubes | Average Crushing Strength Lbs. per Sq In. | Beams | | Yield in Terms of Broken Stone | Cost Dollars per Cu. Yd. |
|---|---|---|---|---|---|---|---|---|---|---|
| | Cement | Sand | Broken Stone | Days | | | Load at Center Lbs. | Mod. of Rupture Lbs. per Sq. In. | | |
| 31 | 1 | 4 | 11 | 7 | 21950 | 610 | | | 103 % | 2.71 |
| 32 | | | | 30 | 25400 | 700 | | | | |
| 33 | | | | 90 | 33700 | 930 | | | | |
| 34 | 1 | 4 | 12 | 7 | 22000 | 610 | | | 100 | 2.67 |
| 35 | | | | 30 | 30600 | 850 | 1640 | 205 | | |
| 36 | | | | 90 | 35500 | 980 | 2720 | 340 | | |
| 37 | 1 | 5 | 10 | 7 | 21100 | 585 | | | 109 | 2.83 |
| 38 | | | | 30 | 30400 | 845 | 2520 | 315 | | |
| 39 | | | | 90 | 34000 | 945 | 2890 | 361 | | |
| 40 | 1 | 5 | 12 | 7 | 20100 | 560 | | | 104 | 2.63 |
| 41 | | | | 30 | 28700 | 800 | 2150 | 269 | | |
| 42 | | | | 90 | 44600 | 1250 | 2700 | 338 | | |
| 43 | 1 | 5 | 14 | 7 | 19100 | 530 | | | 100 | 2.54 |
| 44 | | | | 30 | 27400 | 760 | 2180 | 273 | | |
| 45 | | | | 90 | 29800 | 830 | 2110 | 264 | | |

# TABLE II. (Continued)

| No. | Proportion | | | Age | Average | Average | Beams | | Yield in | Cost |
|---|---|---|---|---|---|---|---|---|---|---|
| | Cement | Sand | Broken Stone | Days | Max. Load on Cubes | Crushing Strength Lbs. per Sq. In. | Load at Center Lbs. | Mod. of Rupture Lbs. per Sq. In. | Terms of Broken Stone | Dollars per Cu. Yd. |
| 46 | 1 | 5 | 16 | 7 | 15400 | 430 | | | 100 % | 2.40 |
| 47 | | | | 30 | 25100 | 700 | 1050* | | | |
| 48 | | | | 90 | 28800 | 800 | 2120 | 265 | | |
| 49 | 1 | 6 | 14 | 7 | 16400 | 455 | | | 100 | 2.59 |
| 50 | | | | 30 | 31700 | 880 | 2000 | 250 | | |
| 51 | | | | 90 | 34000 | 945 | 1590 | 200 | | |
| 52 | 1 | 6 | 16 | 7 | 15150 | 420 | | | 100 | 2.44 |
| 53 | | | | 30 | 22400 | 620 | 1320 | 165 | | |
| 54 | | | | 90 | 35000 | 970 | 1640 | 205 | | |
| 55 | 1 | 6 | 20 | | | | | | | 2.22 |
| 56 | | 8 | 20 | | | | | | | 2.19 |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |

* Defective

of the Philadelphia machine running at slowest speed. The concrete for the beams was made as nearly as possible like that for the cubes. One beam was broken for each of the ages of 30 and 90 days, the results being given in Table II. An attempt was made to break beams composed of natural-cement concrete 7 days old, but they were too weak to give results of any value.

## Relative Strength.

The most interesting conclusion to be drawn from these experiments is that lean mixtures of portland-cement concrete are surprisingly strong—even stronger than the richest natural ordinarily used. It will be noticed that the leanest portland-cement

concrete, a concrete in which the volume of mortar is considerably less than the voids in the aggregate, has greater crushing strength than the richest natural-cement concrete ordinarily used.

The results in Table II also show that a concrete composed of 1 part portland cement, 6 parts sand, and 14 to 16 parts broken stone has as great a transverse strength as a concrete composed of 1 part natural cement, 2 parts sand, and 4 parts broken stone. The results for beams agree substantially with those obtained from crushing cubes, and both seem to prove that a very lean portland concrete is fully as strong as a very rich natural concrete.

## Relative Cost.

The preceding experiments were conducted for the purpose of determining also the relative cost of the two kinds of concrete, since in engineering work the cost of the concrete is as important as the strength. It is generally supposed that for the weaker grades of concrete, the requisite strength can be obtained at a less cost with natural cement than with portland, but the truth of this supposition may well be doubted.

In attempting to compute the cost of concrete, the fact must not be over-looked that the volume of the mass of the concrete may be greater than the volume of the aggregate, even though the volume of the mortar may not be sufficient to fill the voids in the aggregate; in-

other words, the adhesion of the mortar to the aggregate, in general, increases the size of the fragments and thereby makes the volume of the resulting concrete greater than that of the aggregate.

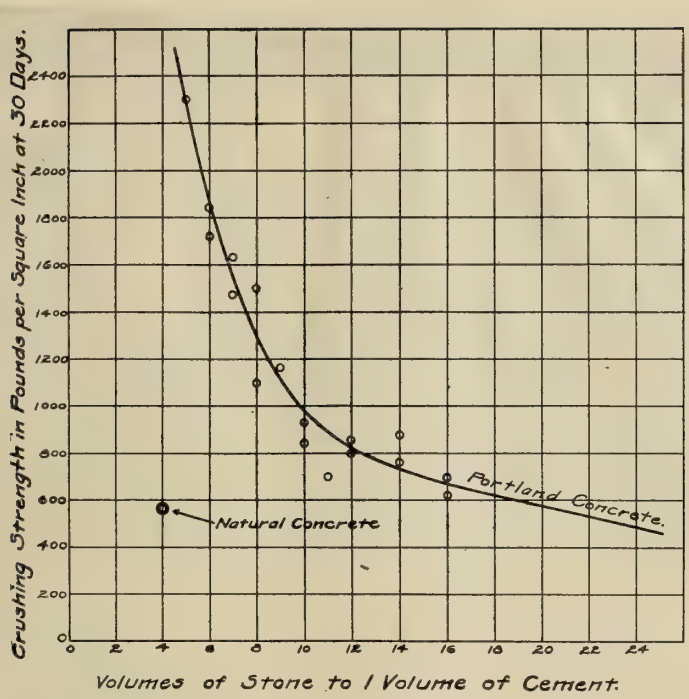
Next to the last column of Table II shows the yield of rammed concrete in terms of the loose stone. Two features of these results are worthy of note. With the richer concretes the yield is approximately 20 per cent more than the volume of the loose stone, and with the leaner mixtures the volume of the resulting concrete is equal only to the volume of the stone. It may be noticed that for the portland cement, the yield for the first four proportions is almost exactly the same as that for the second four. For example, a 1:3:5 and a 1:4:6 portland-cement concrete each give an

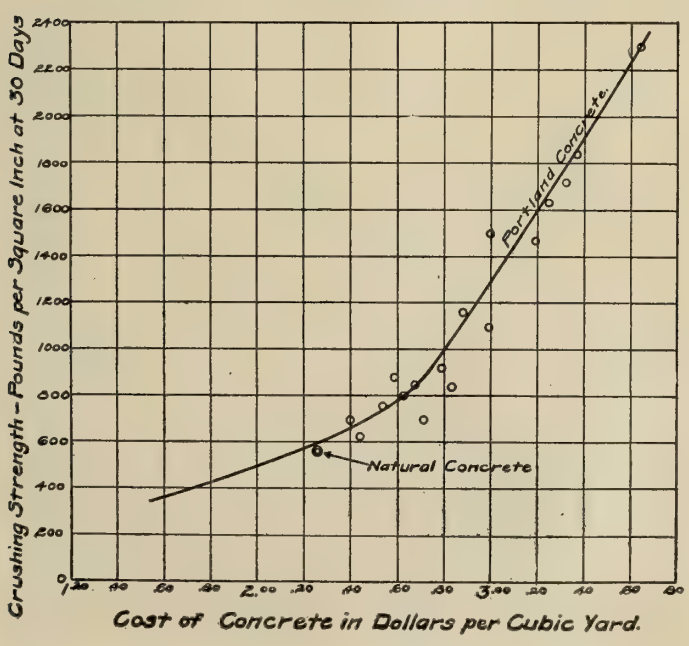
approximate yield of 120 per cent, while a concrete consisting of 1:4 mortar and 6 parts broken stone would be supposed to give a larger yield than a concrete consisting of a 1:3 mortar and 5 parts broken stone. The explanation is that the yield of mortar in terms of the sand is greater for a proportion of 1 part cement to 3 parts sand, than it is for a mortar consisting of 1 part cement and 4 parts sand. A similiar statement is also true for the other proportions in which the yields are apparently the same.

In computing the costs as given in the last column of Table II, the following prices were used: sand, 75 cents per cu. yd.; broken stone, $1.35 per cu. yd.; portland cement, $2.10 per barrel; natural cement, 60 cents per barrel.

Figure 1, plotted from the data in Table II, shows the relation between the strength and the proportion of stone. Notice that for most of the proportions two values are given for the strength of the concrete. These two values are the results for different proportions of sand with the same proportions of broken stone. The diagram also shows that the decrease in strength is very rapid until a proportion of about 1:10 is reached; and that from then on, the curve becomes more nearly horizontal, that is, the decrease in strength is much less rapid.

Figure 2, also from Table II, shows the relation between the strength and the cost of portland cement concrete. It is apparent from this curve that above a cost of about $2.65 per cu. yd., the strength increases more rapidly


Crushing Strength in Pounds per Square Inch at 30 Days.
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0 2 4 6 8 10 12 14 16 18 20 22 24
Portland Concrete.
Natural Concrete
Volumes of Stone to 1 Volume of Cement.


Crushing Strength - Pounds per Square Inch at 30 Days
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1.20 40 60 80 2.00 20 40 60 80 3.00 20 40 60 80
Portland Concrete.
Natural Concrete
Cost of Concrete in Dollars per Cubic Yard.

than the cost; but that below this price, the strength decreases much less rapidly, which shows that a very cheap concrete may have considerable strength. The curve shows that for equal strength, the cost of portland cement and natural cement concretes will be very nearly the same.

While the most interesting feature of the experiments is the surprising strength of the lean portland concretes, it is also important to note that for these lean concretes, the proportion of sand used has but little effect upon either the cost or the strength of the concrete, and that the strength and cost both vary almost directly as the proportion of stone. It appears that below a certain point, the more porous concretes are the most economical, as the addition

of sand increases the cost without giving additional strength.

In conclusion, the experiments show that an unusually lean portland concrete is as strong as a very rich natural concrete. At present prices, concrete of moderate strength can be obtained as cheaply with portland as with natural cement. If portland cement continues to decrease in price as it has in the past few years, it may nearly, if not entirely displace natural cement. Natural cement is sold surprisingly cheap, but it is possible that the price may go still lower in an effort to compete with portland cement.

END

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